Fluid-structure interaction (FSI) simulation of wave travel and reflection in simplified models of the aorta

L. Taelman[a], **J. Degroote**[b], **A. Swillens**[a], **J. Vierendeels**[b], **P. Segers**[a]
[a]*IBiTech-bioMMeda - Ghent University, De Pintelaan 185, 9000 Ghent, Belgium;*
[b]*Department of Flow, Heat and Combustion Mechanics - Ghent University, Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium*
E-mail: Liesbeth.Taelman@UGent.be

Analysis of central aortic hemodynamics, in relation with the stiffness of the large central arteries, is more and more put forward as a way to diagnose cardiovascular risk, a.o. to estimate the effect of the treatment of aortic coarctation (a congenital disease characterized by an obstructive narrowing of the upper descending aorta) on the load on the heart. Due to the complex anatomy and physiology of the arterial system, however, the exact interplay between arterial stiffness, wave travel and reflection is still not fully understood, hampering the interpretation of data. In this study, we use an FSI-model to assess wave travel and reflection in simplified models of an aortic coarctation with increasing degree of complexity in terms of geometry and mechanical properties.

Two simplified models of a normal aorta were studied. The first model consists of a uniform tube with a length of 40 cm, a diameter of 1.5 cm, a wall thickness of 0.15 cm and a Young modulus (E) of 250 kPa, yielding a theoretical pulse wave velocity (PWV_{th}) of 4.88 m/s. The second model has the same length and ratio of wall thickness to diameter but tapers from a diameter of 2 cm at the inlet to 0.94 cm at the outlet. E increases from 201 kPa to 300 kPa along the tube, yielding an average PWV_{th} of 4.88 m/s. The effect of the repaired aortic coarctation is modeled by including a 5 cm long stiff segment in both models, 15 cm distal to the inlet. A short sinusoidal pressure pulse was imposed at the inlet (30 ms wide, peak 1466 Pa), representative for the foot of a physiological pulse wave. Effects of reflection due to aortic tapering and the presence of the rigid segment were isolated via suppression of reflected waves at the distal end.
The governing equations for the blood flow and the deformation of the tube are solved with two separate codes, which are strongly coupled with the IQN-ILS technique [1].

Our simulations demonstrate the presence of so-called precursor waves, traveling within the arterial wall at a speed approximately 3 times higher than PWV_{th} (16.5 m/s) (see Figure 1). We assessed wave reflections using wave intensity analysis. In the straight tube, the presence of the stiff segment induces a backward compression wave, immediately followed by a backward expansion wave. At the outlet, the stiff segment reduces the amplitude of the forward traveling wave by 11%. The backward waves at the inlet of the straight and the tapered tube show more or less the same peaks, but continuous reflections cause overall offsets for the tapered case.

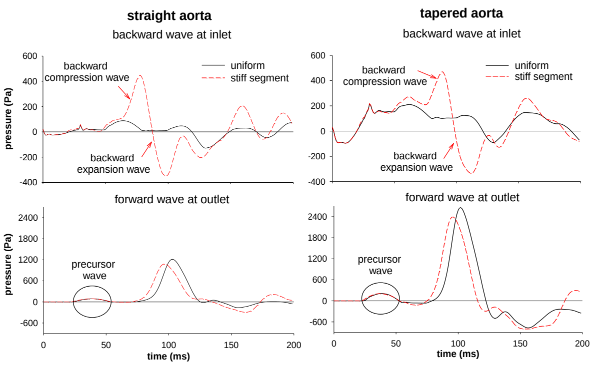

Figure 1. Evolution of the backward waves at the inlet of a uniform and a locally stiffened tube (top); evolution of the forward waves at the outlet (bottom) in both models.

[1]J Degroote, K-J Bathe, and J Vierendeels. Performance of a new partitioned procedure versus a monolithic procedure in fluid-structure interaction; Computers and Structures 87(11-12): 793-801, 2009.